

ECE2277A Lab 1: Implementing Boolean Functions

Professors Arash Reyhani & John McLeod
Prepared by John McLeod

2022 10 03 to 2022 10 14

Objectives

This lab is an exercise in constructing logic circuits from the canonical standard form of a Boolean function, and using Karnaugh mapping (K-maps) to minimize the complexity of this circuit. The objectives of this lab are:

1. To obtain a Boolean function from a set of minterms or maxterms,
2. To use to minimize the complexity of that function,
3. To construct a logic circuit from a Boolean function,
4. To use simulation tools to verify the correctness of that logic circuit, and
5. To implement and test the logic circuit in hardware.

This lab will be done using Quartus, employing the techniques described in Lab 0. The final step is to use Quartus to program the FPGA boards found in the ACEB-2400 laboratory.

Summary

A summary of the deliverables for this lab are enumerated below.

1. Obtain the minimized standard sum of products (SOP) and minimized standard product of sums (POS) forms of a Boolean expression.
2. Implement the lower-cost expression (either SOP or POS) as a logic circuit in Quartus, and use the simulation tools to verify the correctness of that logic circuit.
3. Program the FPGA hardware with your logic circuit, using sliding switches for the inputs and an LED for the output.
4. Show the Quartus design and simulation to your TA, and demonstrate your circuit on the FPGA board.

You must minimize your given Boolean expression to SOP and POS form *before* coming to the lab.

Ideally, you should also implement the Quartus design and simulation *before* coming to the lab, that way you can focus on programming the FPGA board and demonstrating your work to the TA. However, as this lab exercise involves a fairly simple circuit, there should be enough time to complete the project during the lab as long as you are familiar with how to use Quartus.

Grading Scheme

The lab is graded as follows, out of a total of 50.

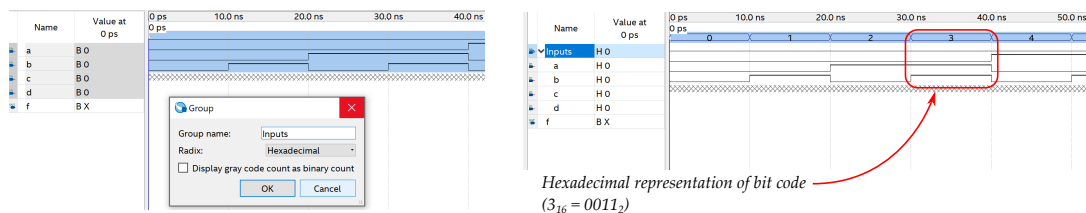
Section	Details	Mechanism	Grade
Minimized Expressions	SOP Expression	Show written work to TA	5
	POS Expression	Show written work to TA	5
Quartus Circuits	Construction	Show Quartus project to TA	15
Quartus Simulations	Simulation	Show Quartus simulations to TA	10
FPGA Hardware	Implementation	Demonstrate working hardware to TA	15

Please bring in evidence of how you minimized the Boolean expression (i.e. a K-map or lines of Boolean algebra) to show the TA. This can be handwritten, printed, on a laptop or tablet, etc.

Quartus Tips

There are some tricks we can use with Quartus to make reading the result from the simulations less of a headache. First, you can group the inputs in the simulation window and express them as a hexadecimal number.

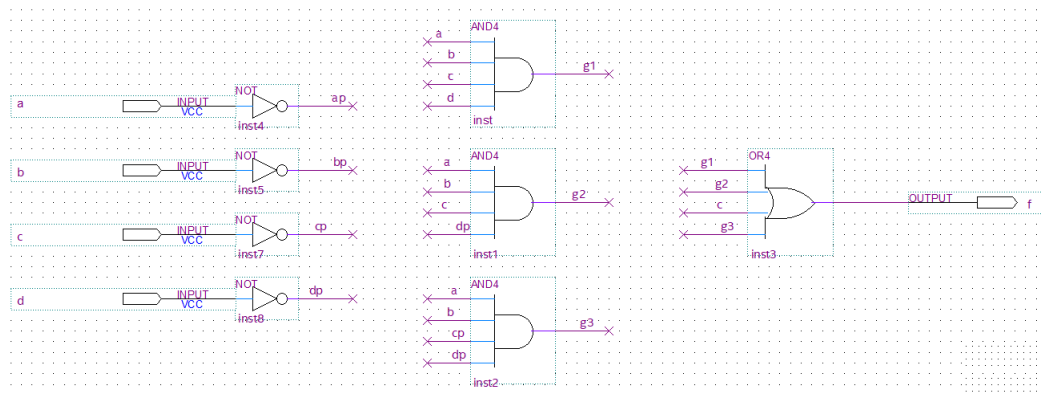
- On the left-hand side of the waveform editor, select all the input pins, then choose Edit→Grouping→Group. Give the group a representative name (like “Inputs”) and select Hexadecimal as the radix.



- This makes it easier to check that the simulation is correct, as the hexadecimal representation of the input bits directly corresponds to the minterm index provided in your function.

You can also label the wires in Quartus, so it is not necessary to physically draw wires connecting each gate. Wires with the same label will be treated as connected by the compiler.

- Draw a short wire from the input and output terminals of each gate.
- Select that wire and type a representative name.
- All dangling wires with the same name will be treated as electrically connected by the compiler. This also holds for the names given to the input pins.



- In the above example, I have input pins a, b, c, and d that are immediately fed into a NOT gate to produce the complements ap, bp, cp, and dp. I then use these labels for the short wires going into my AND4 gates, providing the appropriate minterm.

Following these tips, *especially* grouping the inputs as a hexadecimal number in the simulation, will make checking your work easier.

The laboratory computers in ACEB2400 use Quartus 18.0, while most of you probably have Quartus 20.1. There are (probably) some backwards-compatibility issues between these two versions, so a finished Quartus 20.1 project (probably) won't work in Quartus 18.0. However for these simple lab exercises you don't need the entire project — just the block-diagram schematic file (.BDF) and the pin assignment file (.QSF).

- You can design the logic circuit in Quartus at home (or in the general computer labs), and compile it to make sure there are no errors, *before* your lab session.
- You can bring the completed .BDF file (on Western OneDrive, a USB stick, or whatever) to the lab.
- In the lab, start a new, blank, project with the same name as the one you created previously.
- Transfer the .BDF file into the empty project directory, and open it in your project (*File→Open*).
- Assuming all file names are consistent, and the circuit was correctly designed, you should be able to compile this project in the lab without any issues.

Furthermore, because we need to program the actual FPGA hardware, the pin assignments for input/output are crucial.

- You can carefully make all the pin assignments in your Quartus project at home using the list of pin assignments provided in the lab (for four of the sliding switches and one of the LEDs — make sure you remember which ones you use).
- Once complete, you can export the assignments (*Assignments→Export Assignments...*) to create a .QSF file. I suggest giving this .QSF a **new** name that is not the same as the project.
- You can bring the .QSF file (on Western OneDrive, a USB stick, or whatever) to the lab as well.
- In the lab, transfer the .QSF file into the new project directory, and import it into your project (*Assignments→Import Assignments...*, and find the appropriate file).
- Assuming all file names are consistent, and the circuit was correctly designed, you should be able to recompile this project in the lab with the completed pin assignments without any issues.

You don't have to do these steps before coming to the lab, but it is strongly advised. This will help you make more efficient use of the laboratory time fighting with Quartus to program the FPGA board, instead of fighting with Quartus to design a circuit.

Minterms and Maxterms

This lab involves 4-variable Boolean functions expressed as a canonical sum of minterms (SOM) form:

$$f(w, x, y, z) = \sum (n_0, n_1, n_2, \dots, n_7),$$

where the n_j are the indices of the minterms. When writing minterms or maxterms as expressions of the variables, assume w is the MSb and z is the LSB. Just so there is no confusion, the complete list of minterms and maxterms is given in the table below.

w	x	y	z	Index	Minterm	Maxterm
0	0	0	0	0	$\bar{w}\bar{x}\bar{y}\bar{z}$	$w + x + y + z$
0	0	0	1	1	$\bar{w}\bar{x}\bar{y}z$	$w + x + y + \bar{z}$
0	0	1	0	2	$\bar{w}\bar{x}c\bar{z}$	$w + x + \bar{y} + z$
0	0	1	1	3	$\bar{w}\bar{x}yz$	$w + x + \bar{y} + \bar{z}$
0	1	0	0	4	$\bar{w}x\bar{y}\bar{z}$	$w + \bar{x} + y + z$
0	1	0	1	5	$\bar{w}x\bar{y}z$	$w + \bar{x} + y + \bar{z}$
0	1	1	0	6	$\bar{w}xy\bar{z}$	$w + \bar{x} + \bar{y} + z$
0	1	1	1	7	$\bar{w}xyz$	$w + \bar{x} + \bar{y} + \bar{z}$
1	0	0	0	8	$w\bar{x}\bar{y}\bar{z}$	$\bar{w} + x + y + z$
1	0	0	1	9	$w\bar{x}\bar{y}z$	$\bar{w} + x + y + \bar{z}$
1	0	1	0	10	$w\bar{x}y\bar{z}$	$\bar{w} + x + \bar{y} + z$
1	0	1	1	11	$w\bar{x}yz$	$\bar{w} + x + \bar{y} + \bar{z}$
1	1	0	0	12	$wx\bar{y}\bar{z}$	$\bar{w} + \bar{x} + y + z$
1	1	0	1	13	$wx\bar{y}d$	$\bar{w} + \bar{x} + y + \bar{z}$
1	1	1	0	14	$wxy\bar{z}$	$\bar{w} + \bar{x} + \bar{y} + z$
1	1	1	1	15	$wxyz$	$\bar{w} + \bar{x} + \bar{y} + \bar{z}$

A expression such as $f(w, x, y, z) = \sum (0, 4, 5, 8)$ is therefore:

$$f(w, x, y, z) = \bar{w}\bar{x}\bar{y}\bar{z} + \bar{w}x\bar{y}\bar{z} + \bar{w}x\bar{y}z + w\bar{x}\bar{y}\bar{z}$$

(Of course, this is before minimization.)

Lab Preparation

Each student has been assigned a unique 4-variable Boolean expression presented as a canonical sum of minterms (SOM) with 8 terms. The complete list of minterms by student number is included at the end of this lab manual. To prepare for the in-person lab exercise, please derive the minimized standard SOP and POS forms of your given Boolean expression.

1. Please bring some evidence of your work to the lab for the TA to check. Most of you will probably use a K-map to solve, but if you love manipulating Boolean algebra by hand you can do that too. You can bring in handwritten work, printed work, show the TA work done on a laptop or tablet, or show a digital copy of your work on the lab computer.
2. Also calculate the cost of the SOP and POS forms to identify which one you should implement in Quartus. You should show this work to the TA as well.

You **must** complete this *before* coming to the lab. As noted, it is also recommended that you complete the Quartus design before attending the lab.

Lab Procedure

You should implement and simulate the minimized expression in Quartus, then program the FPGA board with this expression. The circuit should use four slider switches as the inputs and one LED as the output.

1. Create a new project in Quartus. Make sure you use the 5CSXFC6D6F31C6, for the DE10-Standard, as the device when creating the project.
2. Design the appropriate logic circuit obtained in the prelab where $f(w, x, y, z)$ is the lowest-cost minimized form of your Boolean expression.
3. The inputs w , x , y , and z ; should be controlled by slider switches, so make sure the pin assignments follows those given in the table below.

Algebraic Name	Hardware Label on FGPA Board	Pin Name in Quartus
w	SW3	PIN_AC30
x	SW2	PIN_AB28
y	SW1	PIN_Y27
z	SW0	PIN_AB30

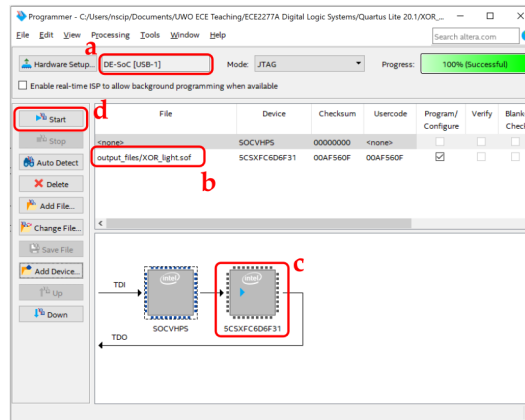
If you want to use different switches for some reason that is fine (there are 10 switches available), just make sure you remember which switch is associated with which input variable. A complete list of the pin names for all switches is available on OWL.

4. The output $f(w, x, y, z)$ should be an LED, so make sure the pin assignment follows that given in the table below.

Algebraic Name	Hardware Label on FGPA Board	Pin Name in Quartus
$f(w, x, y, z)$	LED0	PIN_AA24

If you want to use a different LED for some reason that is fine (there are 10 LEDs available), just make sure you note which one you use. A complete list of the pin names for all LEDs is available on OWL.

5. Compile the project in Quartus and make sure there are no errors.



6. Run a simulation on the circuit to demonstrate that the correct output is obtained for all input combinations.

It is possible to complete all of the above steps on any computer with Quartus before the lab. If you do this, you can show the TA your simulation waveforms with a print out, a screenshot, or on your own laptop — or you can simply repeat the simulations on the lab computer. Remember that it is *always* necessary to compile the project on the lab computers before programming the FPGA board.

7. Program the FPGA board using Quartus (*Tools*→*Programmer*).

- Make sure “DE-SoC (USB 1)” is selected near the *Hardware Setup* button (a). If it is not, press the button and try to find it.
- Make sure a icon representing the ARM Cortex-A9 processor (“hard processor system”, or HPS) is visible. It should be called SOCVHPS, and it should be before the 5CSXFC6D6F31 icon representing the FPGA in the bottom part of the dialog window. If it is not visible, click the *Add Device...* button, and find *SoC Series V*→SOCVHPS in the popup window. (Alternatively, you can mess around with *Auto Detect* button, as I do in the video, but this way is probably more straightforward.)
- Make sure the appropriate .SOF file is present in the middle part of the dialog window (b). If it is not, click the *Add File* button and find it. It should be somewhere in the project directory.
- Make sure the Program/Configure box next to the .SOF file name is checked. If it is not, check it.
- Make sure the 5CSXFC6D6F31 icon representing the FPGA is selected. It should have a blue triangle on it (c). If it does not, click it.
- If everything is done correctly, the *Start* button should be available (d). Click it to start programming. The progress bar will turn green and read *100% Successful* if it worked.

8. Once programming is complete, you can toggle the slider switches on the FPGA board and see how that changes the LED output.

Once your FPGA board is programmed and working correctly, call the TA over to demonstrate your work.

Student Number	Minterms	Student Number	Minterms
250932899	1, 8, 9, 10, 12, 13, 14, 15	251148681	0, 2, 4, 6, 8, 9, 12, 14
250953411	1, 3, 5, 6, 7, 8, 12, 14	251149359	1, 3, 5, 7, 10, 13, 14, 15
250973663	1, 2, 4, 5, 6, 9, 12, 13	251150815	1, 4, 5, 6, 8, 9, 12, 14
251004511	0, 2, 3, 4, 5, 6, 7, 13	251150861	2, 8, 9, 10, 11, 12, 13, 15
251020158	0, 2, 4, 6, 8, 9, 11, 15	251151230	0, 2, 6, 8, 10, 12, 13, 14
251023417	2, 3, 6, 7, 8, 10, 12, 13	251151337	0, 1, 3, 4, 10, 11, 14, 15
251034633	0, 1, 2, 3, 4, 5, 10, 12	251151972	0, 1, 2, 4, 6, 10, 12, 14
251056228	1, 3, 4, 6, 8, 9, 11, 12	251152668	1, 2, 3, 4, 5, 6, 12, 14
251069072	3, 4, 6, 7, 10, 11, 12, 14	251152812	1, 2, 3, 5, 6, 7, 12, 14
251070587	1, 3, 4, 6, 8, 9, 12, 14	251153924	0, 1, 5, 7, 8, 9, 10, 14
251072967	0, 1, 3, 7, 10, 11, 14, 15	251154486	0, 2, 4, 6, 10, 13, 14, 15
251075877	5, 6, 7, 8, 12, 13, 14, 15	251154809	0, 1, 2, 3, 9, 13, 14, 15
251077855	0, 1, 3, 7, 8, 9, 13, 15	251155532	3, 7, 8, 9, 12, 13, 14, 15
251077861	0, 1, 4, 5, 7, 8, 9, 12	251156286	0, 2, 3, 4, 8, 12, 13, 15
251081687	4, 5, 9, 11, 12, 13, 14, 15	251156820	2, 5, 6, 7, 8, 9, 10, 14
251086528	1, 3, 5, 7, 8, 9, 11, 12	251156898	0, 1, 2, 6, 8, 9, 11, 15
251086548	2, 3, 4, 10, 11, 12, 14, 15	251157467	4, 5, 6, 7, 8, 12, 14, 15
251092471	4, 6, 9, 10, 11, 13, 14, 15	251157675	3, 4, 7, 9, 11, 12, 13, 15
251096071	0, 4, 6, 7, 8, 9, 10, 11	251159450	3, 4, 5, 11, 12, 13, 14, 15
251102879	0, 2, 4, 6, 7, 9, 14, 15	251159533	0, 2, 4, 5, 6, 8, 10, 14
251105796	1, 3, 4, 5, 7, 12, 13, 15	251159848	0, 2, 3, 9, 10, 11, 13, 15
251107809	5, 6, 7, 8, 10, 12, 14, 15	251160283	1, 5, 6, 7, 8, 9, 14, 15
251108044	0, 2, 3, 6, 7, 8, 10, 13	251160348	0, 2, 3, 4, 6, 7, 12, 14
251110662	0, 4, 6, 7, 8, 9, 14, 15	251161208	0, 1, 3, 4, 7, 9, 11, 15
251111675	0, 1, 3, 4, 5, 11, 12, 13	251161422	3, 4, 5, 7, 8, 9, 11, 15
251113469	2, 4, 6, 9, 11, 12, 13, 15	251161491	0, 1, 2, 3, 4, 6, 8, 12
251114319	0, 2, 3, 4, 6, 7, 13, 15	251161550	1, 2, 3, 5, 10, 11, 12, 14
251114542	0, 1, 2, 5, 6, 7, 10, 14	251161689	0, 1, 4, 5, 8, 10, 13, 15
251116267	0, 1, 4, 5, 6, 7, 13, 15	251162103	0, 2, 3, 7, 9, 11, 13, 15
251118436	2, 3, 6, 9, 11, 13, 14, 15	251162258	0, 1, 2, 5, 6, 9, 13, 14
251127801	0, 1, 3, 5, 6, 7, 14, 15	251162417	0, 1, 3, 4, 6, 8, 9, 11
251130737	2, 5, 6, 7, 8, 10, 12, 14	251163615	0, 2, 3, 4, 6, 7, 10, 11
251130750	4, 5, 6, 7, 10, 13, 14, 15	251163911	0, 1, 2, 3, 8, 12, 13, 15
251132469	1, 3, 5, 6, 7, 8, 10, 14	251163969	0, 1, 4, 8, 9, 10, 11, 12
251135529	4, 5, 7, 8, 10, 12, 13, 14	251164593	4, 5, 9, 10, 11, 12, 13, 14
251137738	0, 2, 6, 8, 10, 11, 14, 15	251165603	1, 2, 3, 4, 6, 9, 10, 11
251140719	3, 5, 8, 10, 11, 12, 13, 14	251166032	0, 1, 2, 8, 9, 10, 12, 13
251141632	0, 2, 4, 8, 9, 10, 12, 13	251166193	4, 6, 7, 8, 10, 12, 14, 15
251142674	0, 1, 6, 7, 9, 11, 13, 15	251167766	4, 6, 7, 8, 9, 12, 13, 15
251142990	4, 5, 6, 7, 8, 9, 11, 15	251167979	2, 3, 4, 6, 10, 11, 13, 15
251143241	2, 4, 6, 8, 9, 12, 13, 14	251168120	0, 2, 4, 6, 9, 11, 14, 15
251143509	0, 2, 3, 8, 10, 11, 13, 15	251168519	0, 2, 5, 7, 8, 9, 13, 15
251143649	1, 5, 10, 11, 12, 13, 14, 15	251168958	1, 2, 5, 6, 10, 12, 13, 14
251144546	1, 2, 3, 5, 6, 7, 9, 11	251169680	1, 2, 3, 5, 9, 10, 13, 14
251145429	1, 5, 8, 9, 10, 11, 12, 13	251169917	0, 1, 3, 4, 5, 6, 11, 14
251146796	2, 5, 7, 8, 9, 10, 13, 15	251170404	3, 4, 6, 7, 8, 10, 11, 15
251146878	0, 4, 6, 8, 10, 11, 14, 15	251170488	0, 1, 2, 3, 4, 7, 11, 15
251147265	1, 4, 5, 6, 9, 10, 13, 14	251170536	3, 4, 6, 7, 8, 9, 11, 15
251147808	1, 5, 6, 7, 10, 11, 14, 15	251170607	0, 3, 4, 7, 12, 13, 14, 15
251147928	1, 4, 5, 8, 9, 10, 11, 13	251170731	1, 3, 8, 9, 12, 13, 14, 15
251148008	4, 5, 6, 10, 11, 12, 13, 14	251170814	1, 2, 5, 6, 9, 13, 14, 15
251148040	0, 2, 3, 6, 7, 8, 12, 13	251170914	0, 1, 2, 6, 8, 9, 13, 15

Student Number	Minterms	Student Number	Minterms
251171536	2, 3, 5, 8, 10, 11, 12, 14	251210129	0, 2, 3, 4, 5, 7, 8, 10
251171715	0, 1, 5, 7, 8, 10, 12, 14	251210457	0, 1, 2, 5, 9, 11, 13, 15
251171977	0, 3, 4, 7, 11, 12, 14, 15	251210520	5, 6, 7, 8, 9, 10, 11, 13
251173997	0, 1, 3, 4, 6, 7, 8, 9	251210842	2, 6, 8, 9, 10, 11, 12, 13
251174116	1, 2, 5, 6, 7, 9, 10, 13	251210870	0, 1, 3, 4, 5, 6, 12, 14
251174220	1, 3, 4, 5, 6, 7, 12, 13	251211859	1, 2, 3, 4, 6, 9, 12, 14
251174225	0, 2, 6, 7, 8, 12, 14, 15	251212070	0, 4, 5, 7, 8, 9, 11, 12
251175116	6, 7, 8, 9, 11, 12, 14, 15	251212100	0, 2, 3, 4, 6, 11, 12, 14
251176075	0, 1, 4, 6, 8, 9, 12, 13	251212524	0, 4, 8, 9, 10, 11, 12, 15
251176195	2, 3, 6, 7, 8, 10, 13, 15	251212678	0, 1, 2, 3, 7, 8, 9, 15
251178210	0, 2, 4, 5, 7, 12, 13, 15	251212737	3, 5, 7, 10, 11, 13, 14, 15
251178787	2, 3, 6, 7, 8, 12, 13, 15	251212900	2, 5, 6, 7, 8, 12, 13, 15
251179026	0, 1, 3, 4, 5, 11, 13, 15	251213117	0, 2, 3, 7, 8, 9, 10, 13
251179421	2, 3, 4, 5, 10, 11, 13, 15	251213177	4, 6, 8, 9, 10, 11, 12, 13
251181078	0, 2, 8, 9, 11, 12, 13, 15	251213277	1, 3, 5, 7, 9, 11, 14, 15
251181691	0, 1, 3, 5, 7, 8, 9, 14	251213353	4, 5, 8, 9, 10, 11, 12, 14
251181948	0, 2, 3, 4, 6, 10, 11, 13	251213391	0, 1, 2, 6, 9, 10, 13, 14
251182208	0, 8, 10, 11, 12, 13, 14, 15	251214185	4, 5, 6, 9, 11, 13, 14, 15
251186620	1, 2, 3, 6, 7, 9, 11, 14	251214750	2, 3, 6, 7, 10, 11, 12, 14
251190861	0, 2, 4, 5, 11, 12, 13, 15	251214869	2, 4, 5, 6, 8, 9, 10, 14
251192542	1, 3, 5, 7, 8, 10, 12, 13	251214954	4, 6, 7, 9, 11, 13, 14, 15
251196795	4, 5, 6, 9, 11, 12, 13, 14	251215072	1, 3, 4, 9, 11, 12, 14, 15
251199018	2, 3, 4, 6, 7, 12, 13, 14	251215184	0, 2, 6, 7, 8, 9, 10, 11
251199593	0, 4, 5, 6, 7, 8, 10, 11	251215223	2, 3, 6, 7, 9, 11, 14, 15
251200454	1, 5, 8, 9, 10, 11, 13, 15	251215230	0, 1, 2, 3, 7, 8, 12, 15
251201408	0, 1, 2, 6, 10, 13, 14, 15	251215259	6, 7, 8, 10, 11, 12, 14, 15
251201502	1, 3, 4, 5, 8, 10, 12, 13	251215295	2, 4, 6, 8, 9, 10, 11, 14
251201585	0, 2, 6, 8, 9, 11, 13, 15	251215442	1, 2, 3, 4, 5, 6, 10, 14
251201596	0, 1, 2, 3, 8, 9, 11, 15	251215445	2, 4, 5, 6, 7, 10, 11, 14
251201874	0, 2, 4, 5, 6, 7, 8, 9	251215703	0, 2, 5, 7, 8, 10, 11, 15
251202528	0, 2, 6, 8, 10, 13, 14, 15	251216335	0, 1, 2, 3, 5, 8, 9, 13
251202543	1, 7, 8, 9, 10, 12, 14, 15	251217150	3, 4, 5, 7, 12, 13, 14, 15
251202776	0, 2, 3, 4, 7, 8, 12, 15	251217459	1, 4, 5, 8, 9, 10, 11, 12
251202917	0, 1, 2, 3, 7, 10, 14, 15	251217812	1, 3, 6, 8, 9, 11, 12, 14
251202930	0, 1, 4, 5, 9, 11, 12, 14	251217987	0, 2, 3, 4, 5, 6, 12, 13
251203371	0, 1, 6, 8, 9, 11, 14, 15	251218050	0, 1, 4, 5, 9, 13, 14, 15
251203563	0, 2, 5, 7, 10, 11, 13, 15	251218076	0, 4, 6, 7, 8, 10, 11, 12
251203728	2, 3, 6, 7, 11, 12, 13, 15	251218879	1, 2, 3, 5, 7, 8, 10, 12
251203760	2, 6, 7, 8, 9, 10, 12, 13	251219057	2, 3, 6, 8, 9, 12, 13, 14
251205049	0, 1, 3, 4, 9, 11, 13, 15	251219098	0, 5, 7, 8, 9, 11, 13, 15
251205178	2, 4, 5, 6, 9, 10, 13, 14	251219111	2, 3, 4, 5, 9, 10, 11, 13
251205994	0, 1, 4, 5, 10, 11, 13, 15	251219734	0, 1, 4, 9, 11, 12, 13, 15
251206142	2, 3, 5, 6, 7, 11, 13, 15	251219745	2, 6, 7, 8, 10, 12, 14, 15
251206286	0, 1, 2, 4, 5, 8, 10, 11	251219809	0, 4, 5, 7, 10, 11, 14, 15
251206418	2, 4, 6, 9, 10, 11, 12, 14	251219820	0, 1, 2, 3, 7, 12, 14, 15
251208258	4, 5, 7, 8, 9, 10, 11, 12	251219837	0, 1, 4, 5, 7, 10, 14, 15
251208562	0, 4, 10, 11, 12, 13, 14, 15	251220259	1, 3, 4, 5, 8, 9, 11, 12
251208787	1, 3, 4, 6, 9, 11, 14, 15	251220597	0, 1, 2, 3, 9, 11, 14, 15
251209572	1, 4, 5, 6, 7, 9, 13, 15	251220751	1, 5, 6, 7, 8, 9, 10, 13
251209988	0, 4, 7, 8, 12, 13, 14, 15	251220789	6, 7, 8, 9, 10, 11, 12, 14
251210003	0, 1, 2, 3, 5, 13, 14, 15	251220862	1, 3, 4, 5, 6, 9, 11, 14
251210063	0, 1, 2, 3, 6, 12, 13, 14	251220864	5, 6, 7, 8, 9, 10, 11, 14

Student Number	Minterms	Student Number	Minterms
251221141	2, 3, 6, 9, 10, 11, 13, 15	251232141	4, 5, 6, 7, 9, 10, 11, 13
251221581	0, 1, 8, 9, 10, 12, 14, 15	251232345	1, 2, 3, 6, 8, 9, 10, 14
251222088	2, 4, 6, 10, 11, 12, 14, 15	251232801	2, 4, 5, 8, 9, 10, 12, 13
251222188	2, 6, 7, 9, 10, 11, 14, 15	251233092	1, 3, 5, 9, 10, 11, 14, 15
251222232	1, 3, 5, 6, 7, 9, 13, 14	251233145	2, 5, 6, 8, 9, 10, 13, 14
251222436	0, 1, 2, 4, 6, 9, 13, 15	251233178	0, 1, 2, 4, 6, 9, 10, 11
251222480	1, 2, 3, 4, 5, 10, 12, 13	251233412	5, 8, 10, 11, 12, 13, 14, 15
251222969	2, 3, 6, 7, 9, 10, 11, 13	251233569	1, 3, 5, 9, 11, 12, 13, 14
251223010	0, 1, 4, 5, 7, 8, 12, 15	251233909	4, 6, 8, 9, 11, 12, 13, 15
251223636	0, 2, 3, 7, 8, 9, 11, 15	251234323	0, 1, 2, 3, 5, 6, 7, 13
251223981	0, 1, 2, 4, 6, 8, 9, 15	251234371	0, 1, 2, 3, 6, 10, 12, 14
251224110	4, 5, 6, 7, 8, 10, 14, 15	251234411	0, 1, 4, 5, 7, 8, 9, 15
251224124	0, 2, 3, 4, 6, 10, 11, 12	251234559	5, 6, 7, 8, 10, 13, 14, 15
251224131	0, 2, 8, 10, 11, 13, 14, 15	251234771	0, 1, 2, 4, 5, 8, 10, 15
251224132	0, 1, 5, 7, 8, 10, 13, 15	251235871	1, 3, 5, 7, 8, 10, 11, 15
251224235	1, 2, 3, 6, 8, 10, 12, 14	251236420	1, 4, 5, 6, 10, 11, 14, 15
251224571	2, 3, 6, 7, 8, 10, 11, 12	251236621	0, 1, 4, 5, 8, 9, 11, 12
251224856	1, 3, 6, 7, 9, 11, 12, 13	251236768	0, 2, 7, 8, 10, 12, 13, 15
251224904	1, 3, 4, 5, 7, 8, 10, 12	251236776	0, 1, 8, 9, 10, 12, 13, 14
251225561	2, 3, 9, 10, 11, 12, 13, 15	251237040	3, 5, 7, 8, 10, 12, 13, 14
251225615	5, 7, 10, 11, 12, 13, 14, 15	251237110	0, 1, 3, 4, 5, 7, 10, 11
251225630	2, 6, 8, 9, 10, 11, 14, 15	251237205	2, 5, 7, 9, 10, 11, 13, 15
251225635	2, 4, 5, 6, 7, 10, 13, 14	251237447	2, 3, 4, 6, 10, 11, 14, 15
251226103	1, 2, 3, 9, 10, 11, 14, 15	251237664	1, 2, 3, 4, 5, 6, 10, 11
251226488	0, 2, 3, 7, 8, 11, 12, 15	251237747	0, 2, 3, 5, 7, 8, 13, 15
251226583	0, 4, 5, 7, 8, 11, 12, 15	251237793	0, 1, 5, 7, 10, 13, 14, 15
251226610	6, 7, 8, 10, 12, 13, 14, 15	251238497	1, 6, 7, 8, 9, 10, 14, 15
251226611	0, 2, 5, 6, 7, 8, 13, 15	251239036	2, 3, 4, 6, 9, 12, 13, 14
251226694	1, 3, 8, 9, 10, 12, 13, 14	251239091	0, 1, 2, 8, 9, 10, 12, 14
251227317	2, 3, 4, 6, 7, 12, 13, 15	251239120	0, 4, 5, 6, 7, 8, 10, 14
251227483	2, 5, 6, 10, 12, 13, 14, 15	251239204	2, 3, 6, 7, 9, 12, 13, 14
251227631	0, 1, 2, 3, 5, 9, 12, 13	251239373	2, 3, 8, 10, 11, 12, 13, 14
251228069	0, 1, 5, 6, 7, 13, 14, 15	251239485	0, 1, 4, 5, 11, 12, 14, 15
251228374	2, 3, 4, 5, 8, 10, 12, 14	251240205	1, 3, 5, 8, 10, 11, 12, 14
251228644	0, 1, 2, 3, 5, 6, 9, 13	251240593	0, 3, 7, 11, 12, 13, 14, 15
251228698	3, 4, 6, 8, 9, 11, 12, 13	251240718	1, 2, 3, 6, 7, 8, 9, 11
251228885	0, 2, 3, 4, 8, 12, 14, 15	251240872	0, 1, 2, 4, 5, 9, 10, 13
251229072	4, 5, 7, 8, 10, 12, 13, 15	251240943	1, 2, 3, 4, 5, 6, 7, 10
251229332	0, 4, 5, 7, 8, 10, 12, 14	251240954	0, 4, 5, 7, 8, 12, 14, 15
251229353	0, 4, 8, 10, 12, 13, 14, 15	251241676	1, 2, 3, 6, 7, 9, 10, 14
251229483	1, 2, 3, 4, 5, 7, 10, 12	251241714	0, 1, 2, 6, 8, 9, 10, 11
251229580	2, 3, 5, 7, 8, 10, 13, 15	251241741	2, 3, 6, 7, 9, 10, 11, 14
251229733	0, 1, 2, 5, 7, 8, 10, 15	251243541	4, 6, 8, 9, 11, 12, 13, 14
251230047	2, 3, 6, 8, 9, 11, 12, 13	251244695	1, 8, 9, 10, 11, 12, 14, 15
251230177	4, 5, 6, 7, 8, 9, 12, 14	251244760	1, 3, 6, 8, 9, 12, 13, 14
251230295	1, 2, 5, 8, 9, 10, 11, 13	251244778	2, 3, 8, 10, 11, 12, 14, 15
251230378	0, 4, 5, 8, 10, 12, 13, 14	251245005	0, 1, 3, 5, 7, 8, 9, 13
251230759	2, 3, 6, 11, 12, 13, 14, 15	251245044	0, 2, 5, 8, 9, 10, 12, 13
251230913	2, 4, 5, 6, 8, 10, 12, 13	251245390	0, 1, 2, 3, 4, 6, 14, 15
251231667	0, 2, 3, 4, 6, 7, 12, 13	251245626	0, 2, 3, 4, 10, 11, 12, 13
251231707	1, 3, 4, 10, 11, 12, 14, 15	251246155	2, 3, 4, 6, 7, 9, 12, 14
251232112	0, 4, 5, 6, 7, 8, 14, 15	251246184	1, 2, 5, 9, 10, 11, 13, 15

Student Number	Minterms
251246295	0, 1, 2, 3, 6, 7, 11, 15
251246950	4, 5, 6, 7, 9, 10, 11, 14
251247085	1, 6, 7, 8, 9, 12, 14, 15
251247169	2, 4, 5, 6, 7, 10, 12, 14
251248613	6, 8, 9, 10, 11, 13, 14, 15
251248844	1, 3, 5, 9, 10, 11, 13, 14
251249012	1, 3, 4, 5, 7, 12, 13, 14
251249301	1, 2, 3, 9, 10, 11, 12, 13
251249444	0, 3, 4, 5, 6, 7, 8, 11
251253237	0, 4, 6, 7, 12, 13, 14, 15
251253918	1, 4, 5, 6, 8, 9, 10, 11
251255718	0, 2, 5, 7, 8, 9, 12, 13
251255914	1, 3, 6, 7, 8, 9, 10, 11
251260689	0, 2, 3, 6, 7, 8, 9, 10
251260910	0, 2, 3, 7, 8, 10, 14, 15
251261330	2, 4, 5, 6, 9, 11, 12, 13